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PHOTOELECTRIC COLOR SORTING OF VINE–RIPENED TOMATOES

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PREFACE

This research was conducted cooperatively by the Transportation and Facilities Research Division, Agricultural Research Service, U.S. Department of Agriculture, under the general supervision of Earl K. Bowman, Industrial Engineer, and Joseph F. Herrick, Jr., Investigations Leader, Handling and Facilities Research Branch; and by the Market Quality Research Division, Agricultural Research Service, U.S. Department of Agriculture, under the general supervision of Paul L. Harding (retired), Investigations Leader, Horticultural Crops Research Branch.

Tomatoes used in the research were provided by Flavor-Pict Co-op, Delray Beach, Fla. A recording spectrophotometer for making spectral reflectance measurements was made available by the University of Florida Food Science Department. Acknowledgment is made to C. J. Beckwith and M. C. Hoover of the Electric Sorting Machine Division, Mandrel Industries, Inc., for their cooperation concerning the use of the sorting machine. Russell C. Hofmann, laboratory technician, Market Quality Research Division, assisted in conducting the experiments. Most of the statistical computations were made by ARS Biometrical Services Staff, with the assistance of E. J. Koch.

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PHOTOELECTRIC COLOR SORTING OF VINE–RIPENED TOMATOES

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SUMMARY

Because of the high labor cost of manual color sorting vine-ripened tomatoes, and the importance of obtaining uniformity and consistency in the color sorting operation, factors relating to photoelectric color sorting of vine-ripened tomatoes were studied.

A preliminary study was made to develop a technique for objective measurement of surface color of vine-ripened tomatoes. A difference meter with a light reflectance attachment was used to make color readings at the blossom end of the fruit. With this system, a measuring wavelength of 540 nanometers (nm.) and a reference wavelength of 590 nm. resulted in good classification of tomato color at all levels of maturity below the red stage. Two other wavelength combinations, 590-650 nm. and 675–760 nm., measured the color of red tomatoes satisfactorily.

In a series of sorting tests, vine-ripened tomatoes were sorted into four and five color groups by a commercial photoelectric color sorting machine. Uniformly colored tomatoes, entirely red or entirely green, were sorted consistently. Tomatoes between the red and green stages of maturity were successfully sorted into two or three fairly uniform color groups. A consistent sorting of green tomatoes from breakers was difficult because of the particular viewing system used.

In studies of bruising injury, visually detecting a noticeable difference between the amount of bruising in sorted and unsorted fruit was not possible. After 13 days of ripening, tomatoes sorted by the machine had 12.8 percent decay, and a control sample of unsorted fruit had 9.67 percent.

The changes in color of tomatoes that were sorted into four groups by the photoelectric machine were studied by a difference meter during ripening. Significant differences in average color level were found between days of ripening for all color classes when the fruit was below the red stage. Also, color classes differed significantly during ripening until the fruit reached the red stage of maturity.

Coefficients of variation of the reflectance index during ripening of four color-sorted groups ranged from 3.4 to 22.59 percent. The color variation generally decreased as ripening progressed and was greatest in the greener groups.

Factors to be considered in the design of photoelectric color sorting equipment for vine-ripened tomatoes include ease of operation, reliability, and size and capacity of the equipment, and the type of viewing system used.

The use of photoelectric equipment for color sorting vine-ripened tomatoes on a commercial basis involves the comparison of potential benefits with expected costs. Cost factors include machine ownership, operation, and maintenance. The major benefits of photoelectric color sorting are a reduction in labor and an improvement in uniformity and consistency in the color sorting operation.

INTRODUCTION

Various studies have shown the importance of surface color in relation to consumer acceptance of fruits and vegetables (*10, 11, 13, 16*).[1] Color is frequently the most important factor a consumer uses to judge the quality of many products.

Consumer acceptance of tomatoes depends very much on color. In marketing studies of tomatoes, Garrett, and others (*9*) found a significant variation in sales of fresh tomatoes due to the color range available. The reddest lot available was preferred. In another study by Dedolph and Larzelere (*7*), consumers showed a distinct preference for highly colored tomatoes, choosing those showing 80 to 100 percent color most of the time. However, both studies showed that some consumers preferred tomatoes considerably below the red stage, indicating the need for a range in color at the retail level.

Fresh market tomatoes are harvested as mature green tomatoes and as vine-ripened tomatoes. Mature green tomatoes are harvested and shipped before any color beyond green has developed and may range from greenish white to dark green. Vine-ripened tomatoes are harvested at a more mature stage. Market and weather conditions permitting, tomatoes are harvested when color first appears at the blossom end of the fruit. Final ripening occurs during the 7 to 10 days required to move the tomatoes from the shipping point to the consumer(*12*).

Several factors account for the interest in marketing vine-ripened tomatoes. They are usually packaged in units that facilitate direct handling by retailers, eliminating extensive storage and repackaging in the terminal markets. Consumers seem to consider vine-ripened tomatoes superior in quality to mature green tomatoes. Also, it is difficult to distinguish between mature green tomatoes and immature tomatoes; once picked, immature tomatoes may never ripen properly.

Vine-ripened tomatoes are sorted for color at the packinghouse usually by 10 to 15 workers, and are shipped in two or three color groups. Such manual color sorting is naturally subject to human error, and is not always satisfactory. Factors such as eye fatigue, lack of color memory, variations in color, and changes in lighting conditions greatly influence an individual's color sorting decision (*3*).

In a study by Manley and Godwin (*12*), 54 percent of receivers at the terminal markets reported the necessity for repacking the vine-ripened tomatoes after receiving them from the shipping point because of color variations within individual packs. This repacking and regrouping of tomatoes increased handling costs considerably. Also, tomatoes produced in certain areas were preferred to those from other areas for their uniformity of color and maturity.

Increasing the level of shipments of vine-ripened tomatoes seems to depend on developing a marketing system that would insure a tomato of uniform quality, particularly with respect to color and maturity. The marketing of vine-ripened tomatoes has been improved with respect to color and maturity, but more improvement is necessary.

Because of the high labor costs of color sorting tomatoes, and the importance of obtaining uniformity and consistency of color, research was conducted on photoelectric color sorting of vine-ripened tomatoes. The principal objectives of this research were (1) to test the use of photoelectric equipment for sorting vine-ripened tomatoes for color; (2) to conduct ripening studies of vine-ripened tomatoes sorted into color groups by photoelectric equipment; and (3) to study various factors associated with the commercial use of photoelectric equipment for this purpose.

A number of mechanical sorters have been used experimentally to sort fruits and vegetables by light transmittance (*19*) and light reflectance (*2, 14, 15, 17*). Photoelectric equipment for color sorting fresh fruits and vegetables has been used commercially for only a few products. A large number of commercial photoelectric color sorting machines (*1*) have been used in California to sort lemons for several years.[2] More recently, color sorters have been used to a great extent in the sour cherry industry (*18*). However, the use of photoelectric equipment on a commercial basis to sort tomatoes has been very limited. (One firm uses a commercial photoelectric color sorter to sort tomatoes at a repacking plant.[3])

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[1] Italic numbers in parentheses refer to Literature Cited, p. 16.

FRUIT PROCUREMENT AND HANDLING

All tomatoes used in the research described in this publication were of the Floradel variety obtained from a commercial producer of vine-ripened tomatoes at Delray Beach, Fla.

The tomatoes used in photoelectric sorting tests were selected directly from the packing line, on the same day they were picked, to obtain a representative sample of the color range being sorted in a commercial packinghouse. Because the tomatoes had to be transported a considerable distance, they were not sorted until the following day.

DEVELOPMENT OF COLOR MEASUREMENT TECHNIQUE

Because an objective measurement of color was needed to evaluate results of tests using the photoelectric sorting machine, a preliminary study was made to develop a technique for the objective measurement of the surface color of vine-ripened tomatoes at different stages of ripening.

Spectral Reflectance Measurements

A recording spectrophotometer (ASCO Biospect) was used to make reflectance measurements in the wavelength range of 500–780 nanometers on tomatoes at different levels of maturity. Because this instrument measures light transmittance, a fiber optics reflectance attachment (*5*) was used to obtain the reflectance measurements. The reflectance attachment was oriented to the blossom end of the fruit—the area where color changes first show during ripening.

Spectral reflectance curves were made daily on several tomatoes during ripening at 65° F. and a typical curve is shown in figure 1. Although the spectrophotometer output was calibrated in optical density units, the actual readings were taken as relative reflectance values rather than optical density because the reflectance attachment was used.

Other researchers (*6*) have since reported results of a study where spectral transmittance and reflectance curves were used to characterize the maturity of three varieties of tomatoes. Reflectance readings were made in the wavelength range of 200 to 2,000 nm. Most differences in reflectance for tomatoes of varying maturity were found within the visible spectrum, and results were in general agreement with those of the present study.

Difference Meter Measurements

A light transmittance difference meter (*4*) (ASCO Ratiospect) was used to evaluate color changes. Because this instrument measures the difference in optical density of a product between a measuring wavelength and a reference wavelength, it was necessary to choose wavelength combinations that would indicate color in relation to ripening time. From the various spectral curves obtained, three wavelength combinations—540–590 nm., 590–650 nm., and 675–760 nm.—were selected for use with the difference meter. (In each combination, the measuring wavelength is listed first and the reference wavelength last.) The fiber optics attachment was also used with the difference meter to obtain a reflectance index reading.

To determine the response of the difference meter to tomatoes of varying maturity, reflectance readings were made at the blossom end of 120 fruit after 1, 5, 6, 7, and 8 days of ripen-

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[2] M. C. Hoover, ESM Division, Mandrel Industries, Houston, Texas. Personal communication, 1–26–66.

[3] R. D. Gerwe, FMC Corporation, Florida Division, Lakeland, Fla. Personal communication, 5–26–66.

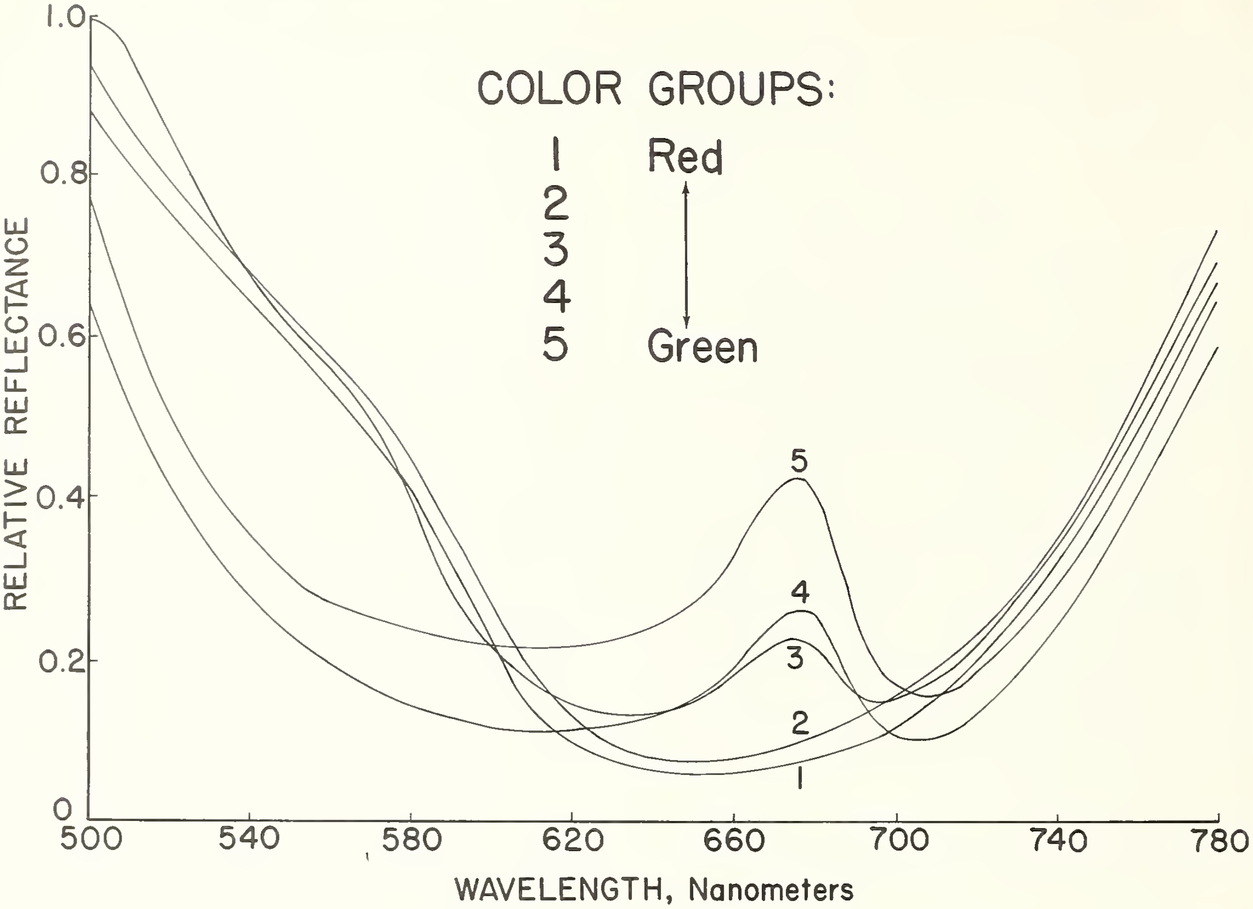

FIGURE 1.—Reflectance curves for tomatoes at different stages of maturity from red (1) to green (5). (Base line of spectrophotometer included in curves.)

ing. Separate readings were made on each tomato for each of the three wavelength combinations. A visual color index for each tomato was recorded when the difference meter measurements were made. The visual color index ratings were based on the following scale:

Index	*Color*	*Description*
1	Green	Entire fruit surface green.
2	Early breaker	White star beginning to show at blossom end.
3	Breaker	Pink beginning to show at blossom end.
4	Light pink	Pink over larger surface; stem end still green.
5	Pink	Overall pink.
6	Light red	Overall light red.
7	Red	Overall red.

After ripening, the tomatoes were separated into seven maturity groups based on the time of initial color change. The three wavelength combinations were compared, based on the average visual color index for seven fruit selected from each maturity group.

Results and Discussion

Average reflectance index values for each group during ripening are shown for the three wavelength combinations in figures 2, 3, and 4. Each wavelength combination gave a relatively good spread in reflectance values in relation to tomato color during the ripening period. By comparing the average index values reflectance with the average visual color index values, which are given in table 1 for each group on each day of ripening, we can see that the 540- to 590-nm. wavelength combination was best for the greener tomatoes and showed good separation between green

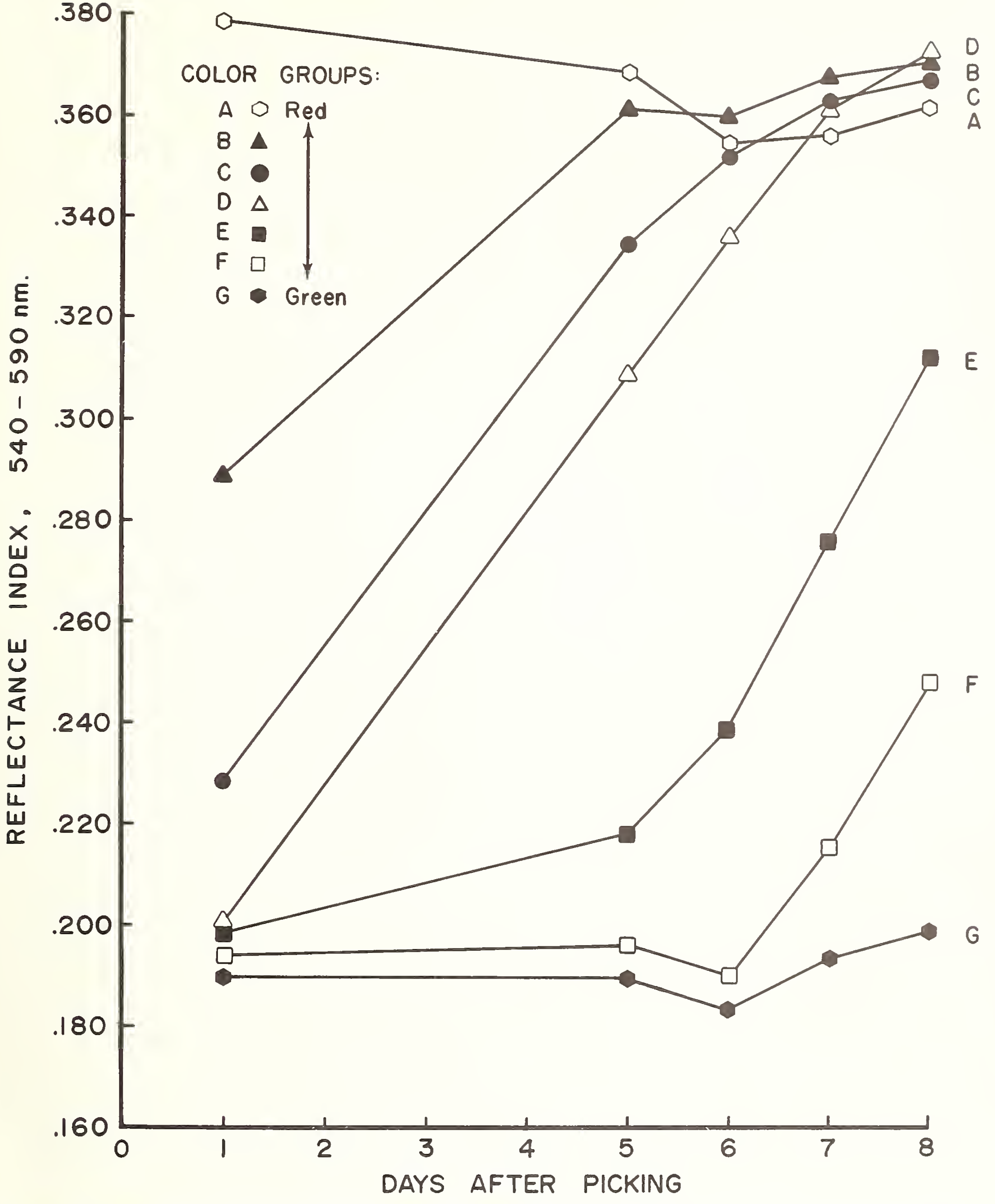

FIGURE 2.—Changes in average reflectance index (540–590 nm.) during ripening of seven color groups of tomatoes. Each color group consists of seven tomatoes from one of the seven maturity groups.

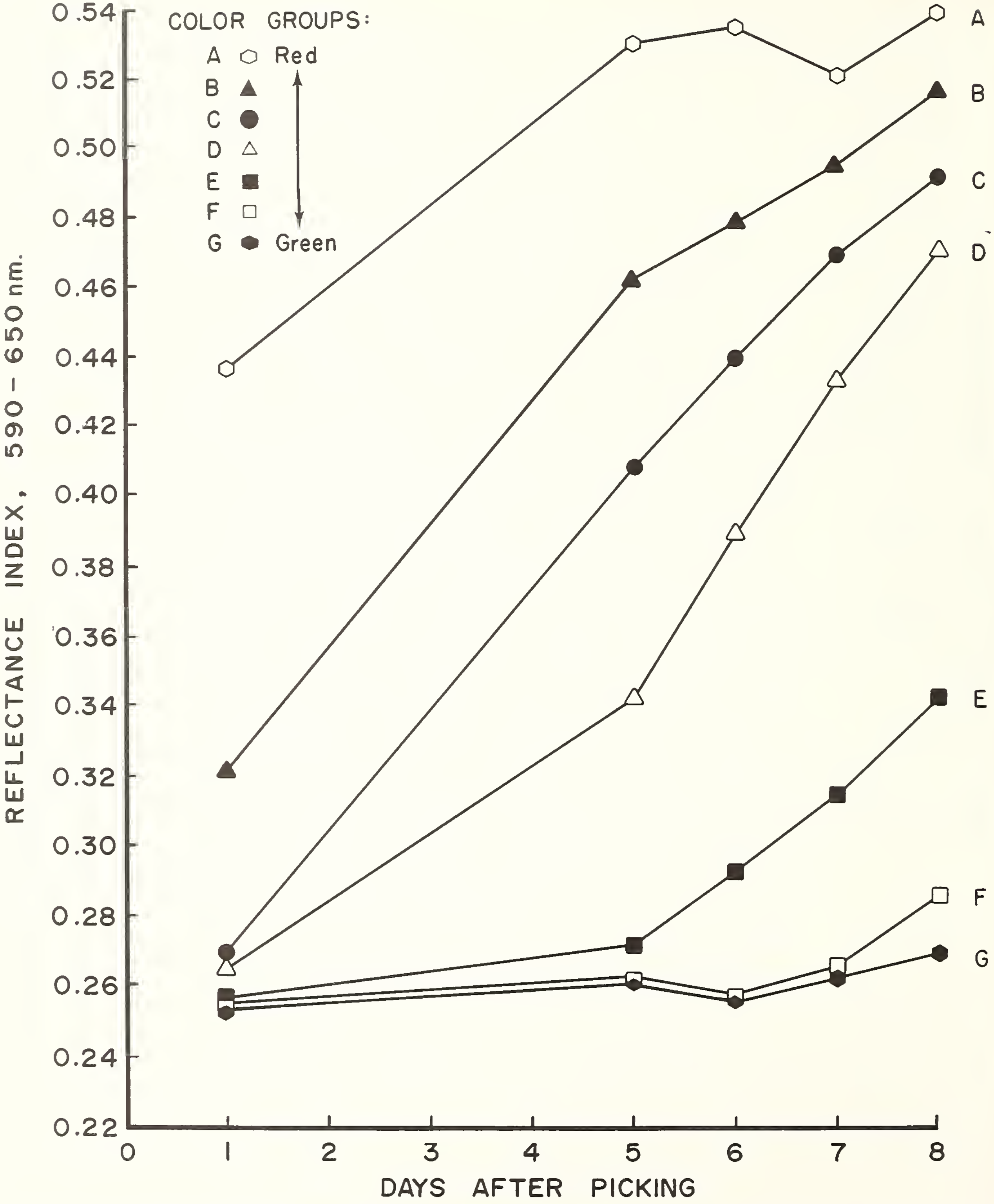

FIGURE 3.—Changes in average reflectance index (590–650 nm.) during ripening of seven color groups of tomatoes. Each color group consists of seven tomatoes from one of the seven maturity groups.

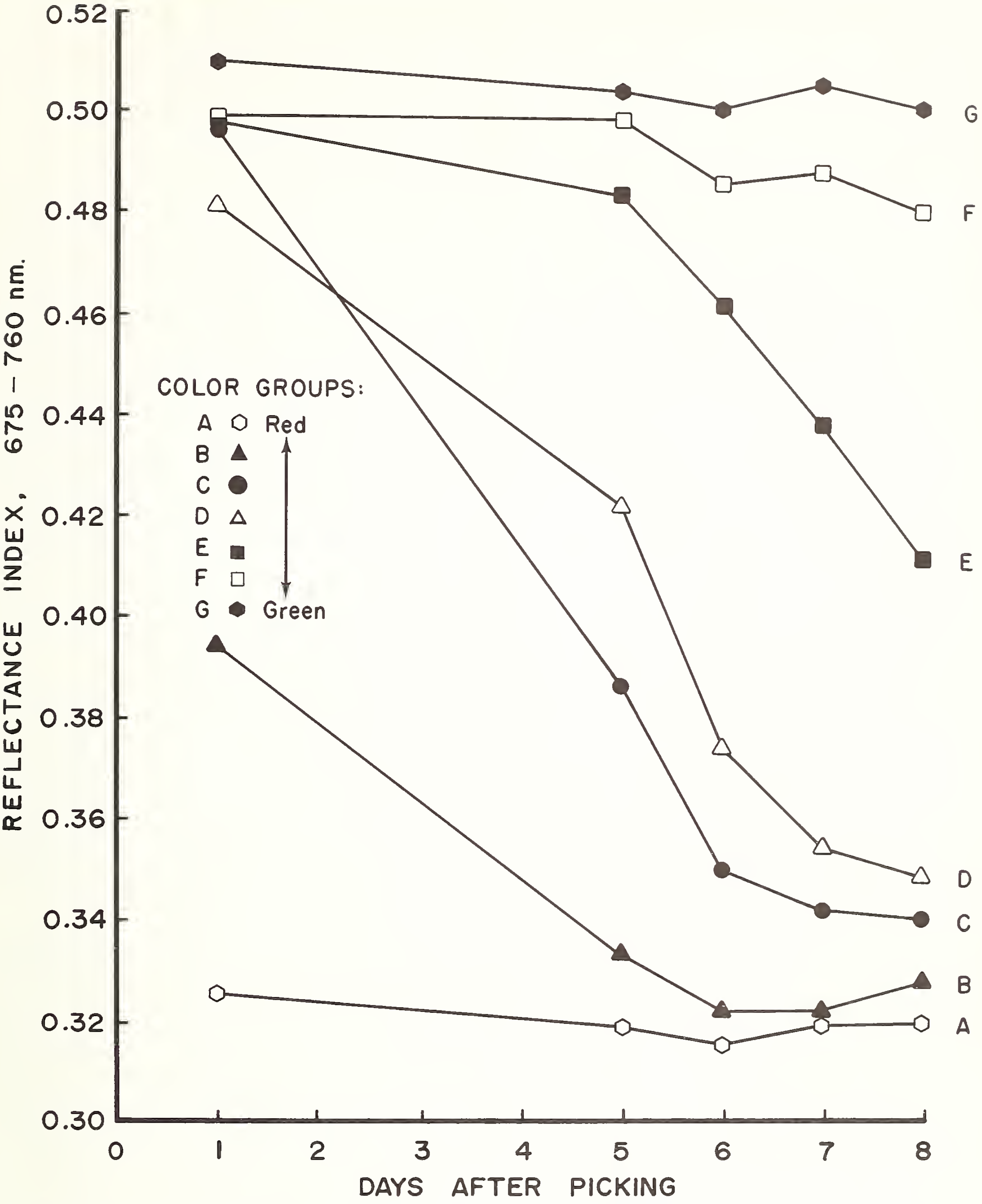

FIGURE 4.—Changes in average reflectance index (675–760 nm.) during ripening of seven color groups of tomatoes. Each color group consists of seven tomatoes from one of the seven maturity groups.

tomatoes and early breakers. This combination also differentiated well between breakers, light pinks, pinks, and light red tomatoes, but did not show good results for the red tomatoes. The other two wavelength combinations differentiated better for the red tomatoes but were not satisfactory for the greener ones.

TABLE 1.—*Average visual color index during ripening of 7 vine-ripened tomato color groups* [1]

Color group	Days after picking 1	5	6	7	8
	Index	*Index*	*Index*	*Index*	*Index*
A	6.0*	7.0*	7.0*	7.0*	7.0*
B	3.0*	5.6	6.4	6.6	6.7
C	2.0*	5.4	5.7	6.1	6.3
D	1.0*	4.0*	4.4	5.0*	5.9
E	1.0*	2.0*	2.7	3.0	4.1
F	1.0*	1.0*	1.0*	2.0*	2.6
G	1.0*	1.0*	1.0*	1.0*	1.0*

[1] * indicates that all tomatoes in group had same visual color index.

Similar results have been reported by Birth, Norris, and Yeatman (*3*), who found that when light transmittance measurements were used as a criterion of tomato color, one wavelength ratio was best for classification of red tomatoes and another was best for classification of green tomatoes. A number of different pigments, including chlorophyll, lycopene, carotene, and xanthophyll combine to produce the color of a tomato (*8*). The fact that the different pigments absorb light at different wavelengths could explain the difficulty in measuring the color of tomatoes over a range of green to dark red using a single wavelength combination.

TESTS WITH PHOTOELECTRIC COLOR SORTING MACHINE

Between January 1966 and February 1967, eight tests were run on sorting vine-ripened tomatoes with a commercial photoelectric color sorting machine, ESM Model G (fig. 5).

Machine Operation

The machine was capable of sorting 420 fruit per minute, continuously, into two to five different color groups. The incoming fruit was separated and dropped one at a time and at a fixed interval through an illuminated viewing chamber (fig. 6). Reflected light was collected, by a system of lenses and mirrors, from three points 120 degrees apart on the fruit. The three light beams were combined and passed into a two-channel optical system, each channel containing a separate photomultiplier tube and optical interference filter. The two-channel optical system enabled the machine to make sorting determinations based on reflected light at two narrow wavelength bands.

Filters used in these tests were recommended by the manufacturer of the sorting machine. One filter had a peak transmittance at 645 nm. with a half-width [4] of 80 nm. The other filter had a peak transmittance at 480 nm. and a half-width of 40 nm. Controls in the electronic system made it possible to vary the proportionate influence of each filter on each color group independently.

The voltage output of each photomultiplier tube was amplified and the signal was sent to a classifier section. The classifier section combined the amplified signals to determine into which color group each fruit should be sorted. Variable controls on the classifier section allowed for changes in the number of color groups and in the range of color to be included in each group.

A signal from the classifier section was stored in a memory device to allow for the time delay between the viewing of the fruit and the actual mechanical separation. After each fruit passed through the viewing chamber, it fell into a padded pocket on a rotating delivery wheel (fig. 5). When this pocket was above the proper delivery point, the signal stored in the memory device activated a trip mechanism to place the fruit onto the proper delivery conveyor according to color group.

The viewing chamber contained three colored backgrounds (fig. 6) that acted as color standards. Because of possible small variations

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[4] Half-width is defined as the spectral width of the pass band at the level where the transmittance is one-half the peak transmittance.

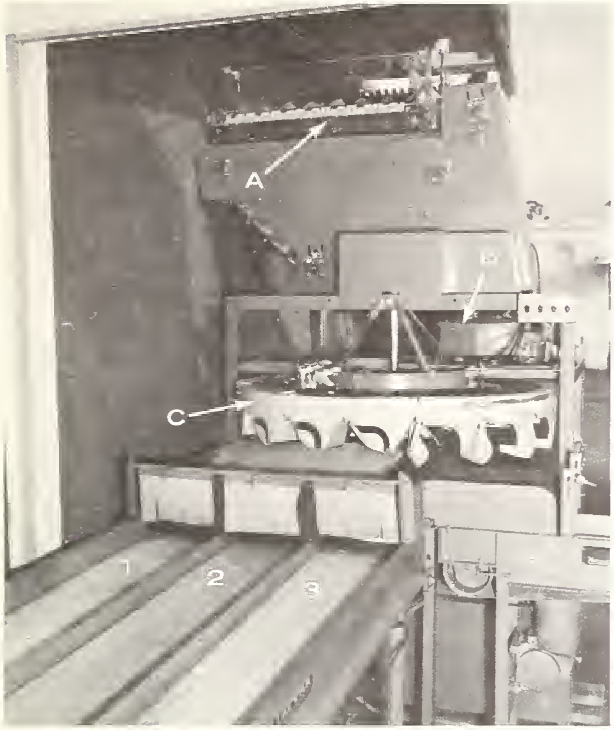

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Figure 5.—Photoelectric color sorting machine. A, separating mechanism; B, optical viewing chamber; C, delivery wheel; 1, 2, 3, and 4, delivery conveyors.

in the electronic circuitry and in the intensity of the light source, the machine could deviate from the desired sorting standard. The photoelectric system viewed the colored backgrounds after every other fruit, with a regulator circuit resetting the amplifier signals to a fixed sorting standard, thus continuously standardizing the sorter.

Sorting Tests

The researchers made various sorting tests on tomatoes to familiarize themselves with the machine's operation and to determine what effect adjusting the controls had on sorting results. The effect of varying the proportionate influence of each filter was determined. When the machine was adjusted for sorting into five groups, best results were obtained when groups 1 (red), 2, and 3 were sorted with 50 percent of each filter, and group 4 was sorted with 30 percent of the 645-nm. filter. Group 5 (green and breakers) was not sorted electronically and was the remainder of the tomatoes not classified in the first four categories. When the tomatoes were sorted into four groups, 1 and 2 were sorted with 50 percent of each filter and group 3 with 30 percent of the 645-nm. filter; group 4 was the remainder not classified in the first three categories.

Tests were also run to determine the range of color that could be sorted and to determine proper settings of the controls to get a uniform color in each group. Uniformity within color groups was fairly good but there was some overlap of color in adjacent groups. Tomatoes that were entirely red or entirely green were consistently sorted into the proper groups, but those with both red and green on them were more difficult to sort consistently. Some tomatoes with both red and green color might not fall into the same group if sorted over and over, because of the design of the optical viewing system. The category into which such a tomato would be sorted depended on the orientation of the tomato as it passed through the viewing system and which color was predominant in the viewing. The most difficult sorting problem was the separation of breakers from tomatoes that were entirely green. A breaker has a small white or pink star at the blossom end and unless the tomato was oriented so that the blossom end was viewed, the viewing system saw only green and sorted it into the green category. The separation of green tomatoes from breakers is very important commercially because a breaker may ripen several days sooner.

In most tests fruit was sorted into four or five color groups, which is analagous to manual sorting in a vine-ripened-tomato packinghouse, where fruit is sorted into four or five groups. Of these, the reddest group is marketed locally, the greenest group is shipped as mature greens, and the remaining groups are shipped as vine-ripened tomatoes.

Results of sorting tests on tomatoes sorted into four and five groups are shown in figure 7.

A test also was made to determine how closely the machine could sort and into how many different groups the tomatoes could be sorted. In this test the machine was adjusted to sort into four uniform color groups. The red

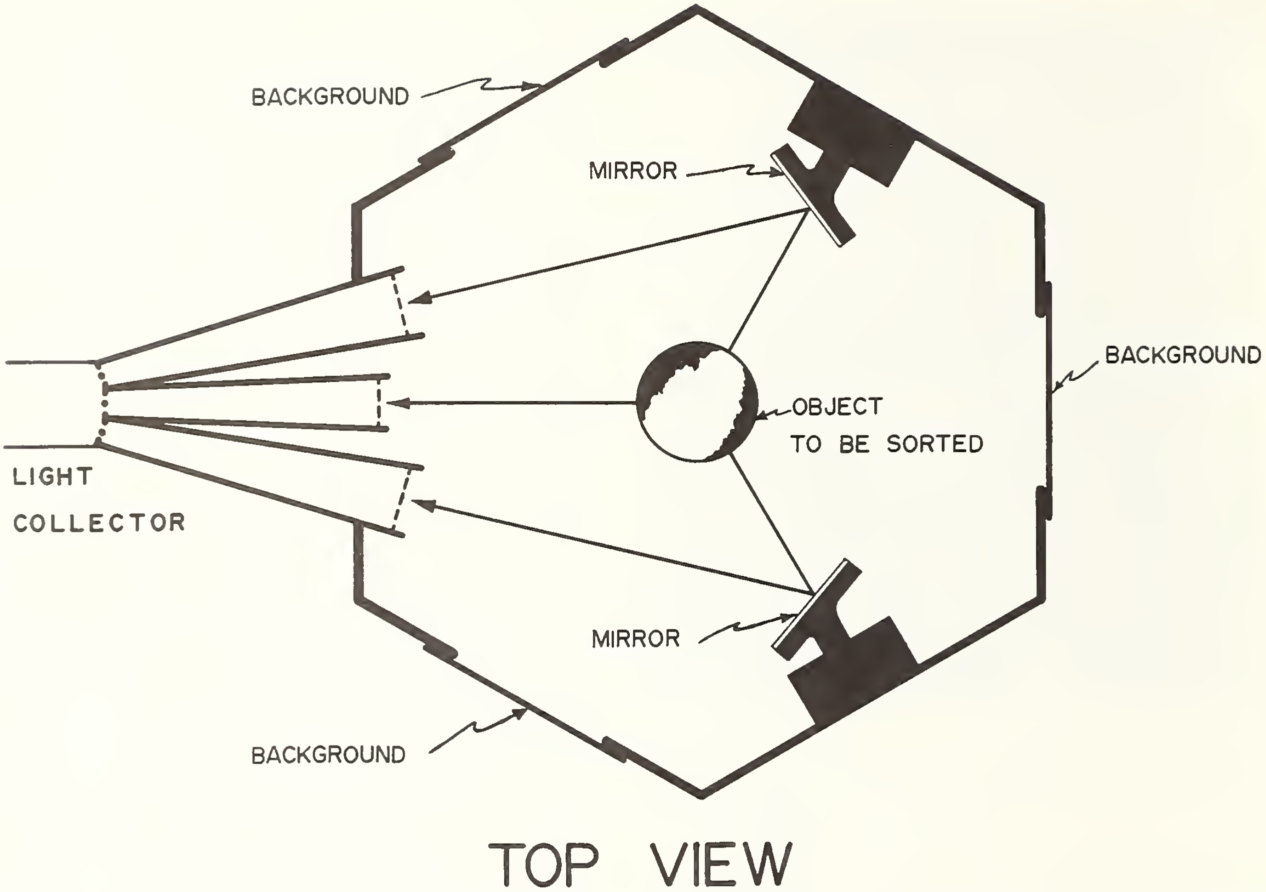

FIGURE 6.—Diagram of optical viewing chamber. Object is illuminated by three lamps above and three below plane shown.

group was held aside and each of the three remaining groups was re-sorted separately into four subgroups, making 13 groups. This was done by readjusting the controls on the classifier section when re-sorting each of the main groups. After sorting, a very slight visual difference could be detected between the average colors for each of the 13 groups. During ripening, the visual differences between subgroups disappeared, although there were still detectable differences in average color between the four main groups throughout ripening.

This test was made only to study the capabilities of this type of photoelectric sorting equipment. It would not be feasible to sort tomatoes into so many groups commercially because of the complications in handling, and also because there would be no advantage in relation to differences in ripening between groups.

Bruising and Decay Studies

Because tomatoes are easily injured by rough handling, tests were run on four occasions to determine if the operation of the machine affected the occurrence of tomato bruising. Because the machine was not specifically designed to sort tomatoes, additional urethane foam padding was placed in the delivery wheel pockets and at the entrance to the delivery conveyors. A large group of tomatoes was sorted by the machine and then held at 60° F. for ripening, along with a sample of equal size that had not been sorted. After several days of

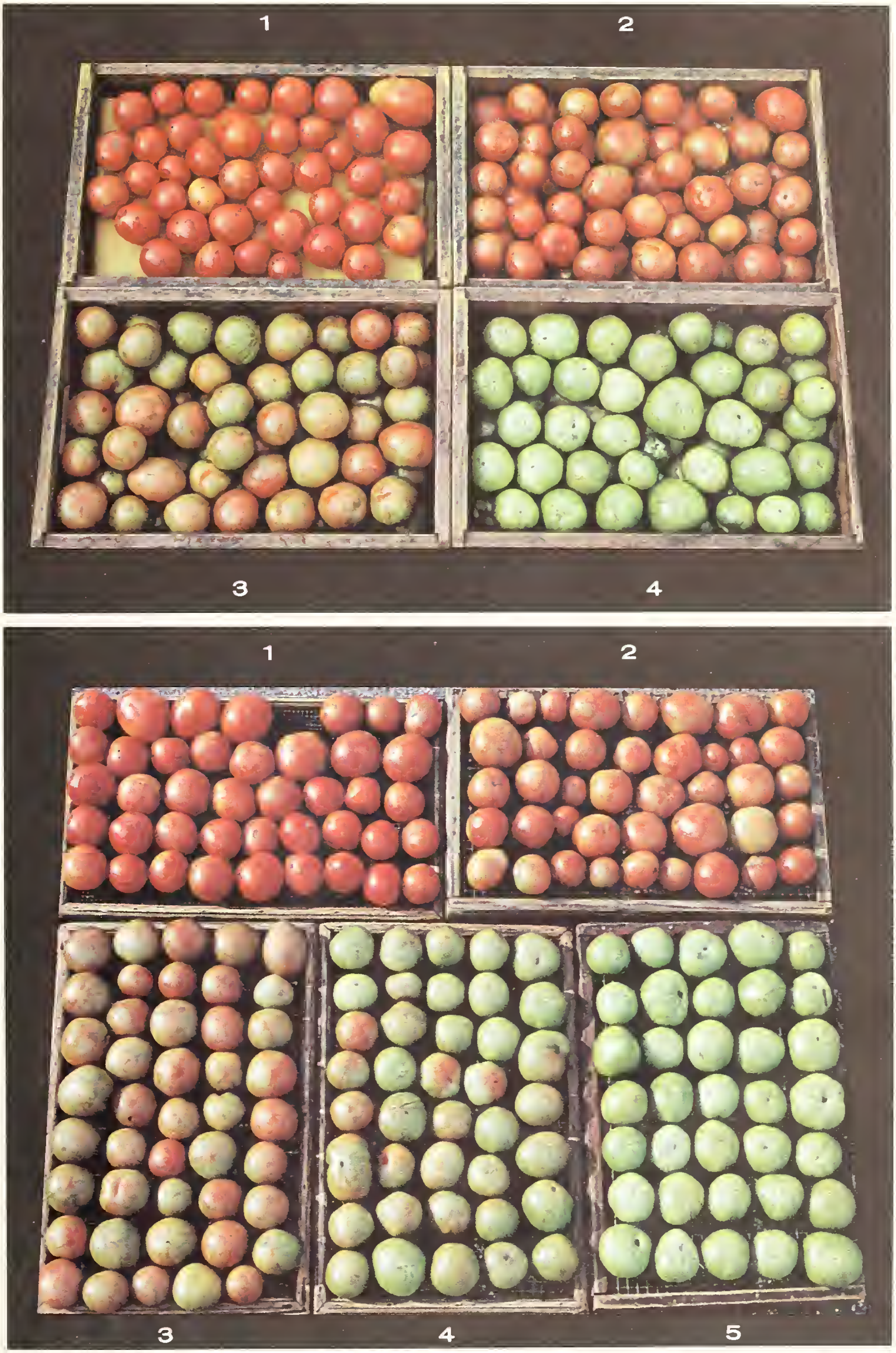

FIGURE 7.—Representative samples of vine-ripened tomatoes sorted into four and five groups by a photoelectric sorting machine.

ripening, the amount of bruising in each lot was compared. There was very little noticeable bruising in either group and it was not possible to visually detect a significant difference between them. What little bruising did occur was only on ripe fruit, which are a small percentage of vine-ripened tomatoes.

Results of other tests indicated that the machine would cause bruising if the fruit were run through it several times. When this was done, bruising was extensive on the red tomatoes. The two main types of bruising injury were a small dent or puncture because the fruit hit a sharp edge, and a general overall softening because of repeated impacts.

The two groups of fruit used for the bruising tests were also checked for decay. The fruit sorted by machine had a higher incidence of decay (bacterial soft rot) than the control sample (table 2). However, the relatively small amount of injury to the tomatoes as a result of sorting was highly encouraging considering the machine was not designed to handle tomatoes. These results indicate that damage would not be a major problem with a handling system designed specifically for tomatoes.

TABLE 2.—*Comparison of percentage of decay (bacterial soft rot) between machine sorted and unsorted vine-ripened tomatoes*

Color group	Days after picking 7	9	13
	Percent	*Percent*	*Percent*
1 Red	12.82	12.82	12.82
2	6.14	9.64	9.64
3	8.16	8.16	18.36
4 Green	4.16	4.16	14.58
Average[1]	7.20	8.80	12.80
Unsorted fruit	3.62	3.62	9.67

[1] This is a weighted average because the number of fruit in each color group was not the same.

TOMATO RIPENING STUDIES

A test was made to study color during ripening to determine if tomatoes could be sorted into color groups so that differences between color groups would remain throughout the ripening period. The tomatoes were sorted into four groups with the photoelectric sorting machine. This test was conducted with four replications, of approximately 300 fruit each, and each replication was sorted separately with the same control settings on the machine. The four color groups were numbered for purposes of identification—group 1, the red fruit, and group 4, green and breakers.

The fruit was sorted into the four groups without concern that the number of fruit in each group be the same. The distribution of tomatoes given in table 3 indicates that the majority of them fell into the middle color groups. In commercial practice, the number of red fruit depends on the time interval between pickings and the number of green fruit depends on how "closely" the tomatoes are picked. Usually, the amount of red and green fruit is small compared with the total.

Twenty fruit were selected from each color group and were numbered for identification. Tomatoes were ripened for 8 days at 65° F. Color measurements of each fruit were made with the reflectance attachment on the difference meter, using the 540- to 590-nm. wavelength combination. The use of this combination enabled the researchers to closely follow the color development of the fruit up to the red stage. Readings were made of the blossom end of each fruit immediately after sorting, and after 2, 3, 4, 7, and 8 days of ripening. Average

TABLE 3.—*Percentage distribution of vine-ripened tomatoes sorted into 4 color groups by a photoelectric sorting machine*

Color group	Replication A	B	C	D	Average[1]
	Percent	*Percent*	*Percent*	*Percent*	
1	14.04	12.24	12.97	10.63	12.51
2	36.78	36.39	42.72	29.43	36.52
3	37.45	37.41	32.91	44.68	37.95
4	11.70	13.94	11.39	15.24	13.01

[1] This is a weighted average because the number of fruit in each replication was not the same.

reflectance index values for the four color groups during ripening are shown in figure 8.

An analysis of variance (table 4) was made using a split plot analysis of the combined data over all 6 sampling days. The results showed significant differences between color classes and between days of ripening. The significant color x days interaction indicates that the effect of days ripening on fruit color was not the same for all color classes, because the greener fruit changed color more than the riper fruit.

A Duncan's multiple range test (table 5) was performed to determine the difference in color level between days of ripening for each color group. Because the reflectance index values were not a good indication of color for the red fruit, the test results are shown only for the fruit below the red stage. These results indicate good differences in color level between days of ripening for the fruit below the red stage and show the consistent relationship between sorted color and ripening time.

A separate analysis of variance was made of the individual fruit data for each day of ripening. Replications were not significantly different on any day of ripening. This indicates that the machine repeatedly sorted the fruit into consistent color groups; this consistency remained throughout ripening. A Duncan's multiple range test was applied to the data to determine the difference in color index between color classes for each day of ripening (table 6). Again, the results are shown only for the fruit below the red category. These results indicate a good difference between color classes until the fruit reached the red stage. This is of commercial importance because tomatoes should be sorted into color groups that maintain their differences in color level during rip-

TABLE 4.—*Combined analysis of variance of reflectance index readings during ripening of vine-ripened tomatoes sorted into 4 color groups by a photoelectric sorting machine*

Source of variation	Degrees of freedom	Mean square	Significance[1]
Total	1,919		
Replications	3	15,599.53	NS
Color	3	417,269.04	**
Replication x color	9	6,206.93	NS
Fruit/replication x color	304	4,728.19	
Days ripening	5	151,295.61	**
Color x days	15	41,916.35	**
Replication x days	15	250.51	NS
Replication x color x days	45	316.24	NS
Residual	1,520	416.92	

[1] ** indicates statistical significance at 1 percent level. NS = not significant.

TABLE 5.—*Differences in reflectance index between days of ripening for vine-ripened tomatoes sorted into 4 color groups by a photoelectric sorting machine*

[Average of 20 fruit in each of 4 replications]

Days after picking	Color group[1] 1	2	3	4
	Index	*Index*	*Index*	*Index*
1	378	353 a	309 c	244 g
2	372	363 b	341 d	265 h
3	378	378	370 e	303 i
4	378	378	381 f	333 j
7	371	373	379 f	357 k
8	377	379	381 f	367 l

[1] Means followed by letters in common are not significantly different at the 5-percent level according to Duncan's multiple range test. Comparisons may be made vertically only.

TABLE 6.—*Differences in reflectance index, during ripening, between 4 color groups of vine-ripened tomatoes sorted by a photoelectric sorting machine*

[Average of 20 fruit in each of 4 replications]

Color group	Days after picking[1] 1	2	3	4	7	8
	Index	*Index*	*Index*	*Index*	*Index*	*Index*
1 Red	378 a	372 e	378	378	371	377
2	353 b	363 f	378 i	378	373	379
3	309 c	341 g	370 i	381 k	379 m	381 o
4 Green	244 d	265 h	303 j	333 l	357 n	367 p

[1] Means followed by letters in common are not significantly different at the 5-percent level according to Duncan's multiple range test. Comparisons may be made vertically only.

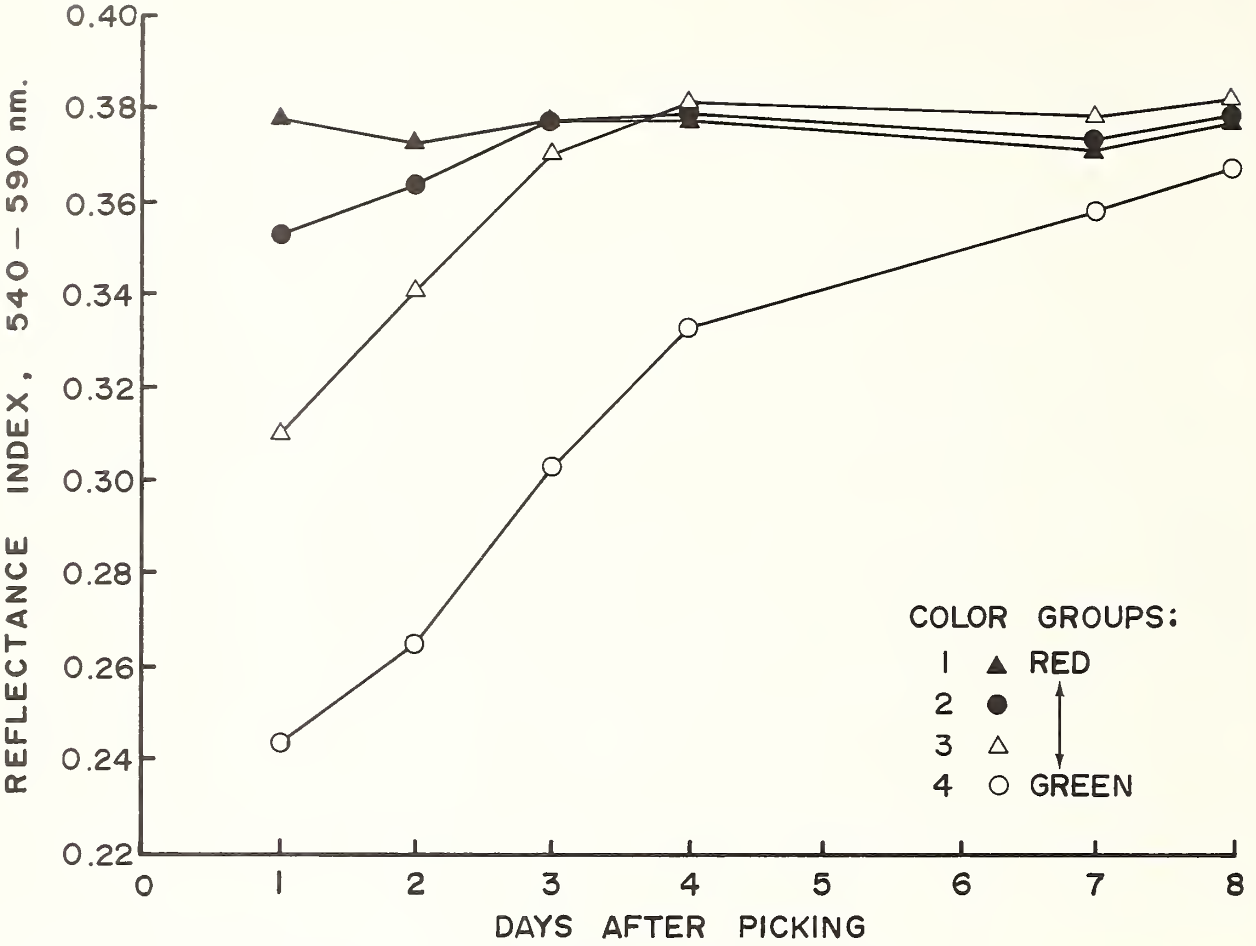

FIGURE 8.—Changes in reflectance index during ripening of vine-ripened tomatoes sorted by a photoelectric color-sorting machine. Average of 20 fruit in each of four replications.

ening. Although the visual color of the four groups was similar after prolonged ripening, subjective tests when the fruit was cut indicated detectable differences in internal appearance and flavor among the groups.

Coefficients of variation (table 7) were calculated on the individual reflectance index readings for the four color groups during ripening. These data indicate the variations in color within each color group on each day of ripening. As ripening progressed, the coefficient of variation generally decreased, indicating that uniformity of color increased as ripening occurred. The coefficient of variation was much higher for group 4 than for the other groups, and the value increased on the second day and then decreased again on subsequent days. The high values in group 4 were probably due to the presence of some fruit that remained green throughout the ripening period.

TABLE 7.—*Coefficients of variation of reflectance index during ripening of vine-ripened tomatoes sorted into 4 color groups by a photoelectric sorting machine*

Color group	Days after picking 1	2	3	4	5	7
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1 Red	4.07	4.49	3.40	3.71	3.74	3.56
2	6.46	4.44	4.17	3.84	3.80	3.76
3	9.82	6.80	5.03	4.13	4.02	4.43
4 Green	18.06	22.59	22.01	20.29	16.65	14.98

CONSIDERATIONS IN EQUIPMENT DESIGN

Several factors are important in the design of photoelectric color sorting equipment for vine-ripened tomatoes. The equipment should be easy to operate, and the checking of circuits and performance of routine maintenance should not require a knowledge of electronics. Reliability is very important, because a breakdown would disrupt succeeding operations in the packing line.

The physical size of photoelectric color sorting equipment may be an important consideration. If the machine were small enough, it could be added to an existing packing line with a minimum of disruption of the packinghouse layout.

Special precautions should be taken in the handling system to minimize physical damage to the tomatoes, which bruise very easily. The equipment should be able to sort tomatoes ranging from 2 to 4 inches in diameter. Variable controls in the electronic system would allow the number of groups and the range of color within each group to be varied as required.

Perhaps a major design consideration is the optical viewing system. One approach would be to view the entire surface of the fruit with many viewed areas. The number of viewed areas would depend on the size of each area, which would in turn depend on the sensitivity of the photoelectric detection system. Then, the photoelectric response from each viewed area would be considered by the system. This seems to be a better method than averaging the color of the entire fruit surface because the color determination could be based on a single color or level of color.

Another approach would be to view only the blossom end of each tomato, where changes in tomato color first appear. This method would be especially suitable for separating green tomatoes from breakers and breakers from pinks. The viewing system would be simplified, since only one viewed area would be required. However, some method of fruit orientation would be necessary so that the viewing system would always "see" the blossom end.

ECONOMIC CONSIDERATIONS

The use of new and improved methods and equipment in fruit and vegetable packinghouses involves consideration of potential benefits against expected costs. The major cost of photoelectric sorting equipment for tomatoes would be the initial equipment cost. Operating and maintenance costs should be low compared with machine ownership cost.

A preliminary study of the cost of manual color sorting in several Florida vine-ripened tomato packinghouses indicated considerable variation in cost among different packinghouses, the lowest cost being approximately 6 cents per hundredweight. On this basis, a packinghouse operating 1,500 hours per year and color sorting 300 cwt. of tomatoes per hour could invest up to $151,840[5] in equipment to replace manual labor. This would include the cost of sorting equipment, as well as any additional cost due to reorganization of packinghouse layout and equipment to handle tomatoes to and from the sorting equipment.

The rate of flow of tomatoes into a packinghouse may range from 1,000 to 2,000 per minute. Photoelectric sorting equipment would not have to handle all of the tomatoes, however, because those of poor grade or inadequate size are removed prior to sorting. Tomatoes that are too ripe or too green—a small portion of the total—are not marketed as vine-ripened tomatoes, and it might be more economical to sort them manually.

The number of sorting machines required in a packinghouse would depend on several factors. These include the volume of tomatoes to be sorted, the number of color groups desired, the capacity of each machine, and the number of color groups that could be sorted by a single

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[5] Computation based on equipment operation and maintenance cost of $0.005 per cwt., annual taxes and insurance of 3 percent of initial equipment cost, 6 percent interest, and a 10-year service life.

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machine. Because a typical packinghouse may ship at least two grades of tomatoes and five or six sizes, the location of the sorting equipment in relation to the grading and sizing equipment must be considered.

A visual inspection of the tomatoes after machine color sorting would be desirable, and perhaps could be done by the graders.

One of the major benefits of photoelectric equipment for color sorting tomatoes would be a reduction in labor costs. Also, properly designed equipment would be able to sort into more color groups, with more consistent uniformity of color within each group, than manual labor can. This might eliminate much of the re-sorting for color at the terminal markets. Photoelectric sorting equipment would give packinghouse operators precise control over the range of color sorted into each group, and the dividing line between color groups could be shifted as desired.

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